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Effect of Mechanical and Thermal Loading Histories on Residual Properties of SiC_f/SiC Ceramic Matrix Composites

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Outline

- Motivation
- Objective
- Approach
- Materials and Properties
- Experimental Set Up
- High-Temperature Results
- Room-Temperature Results
- Fracture Surface Analysis
- Summary & Conclusions

Motivation

SiC_f /SiC Ceramic Matrix Composites (CMCs) are candidates for high-temperature applications such as the new generations of aircraft engines for:

- Reduced component weight (1/3 density of superalloys)
- Higher temperature capability/increased thermal margin
- Reduced cooling requirements
- Improved fuel efficiency
- Reduced emissions (NO_x and CO_2)

Further increase with 2700°F CMC components

Incentive to Increase Engine Operating Temperatures

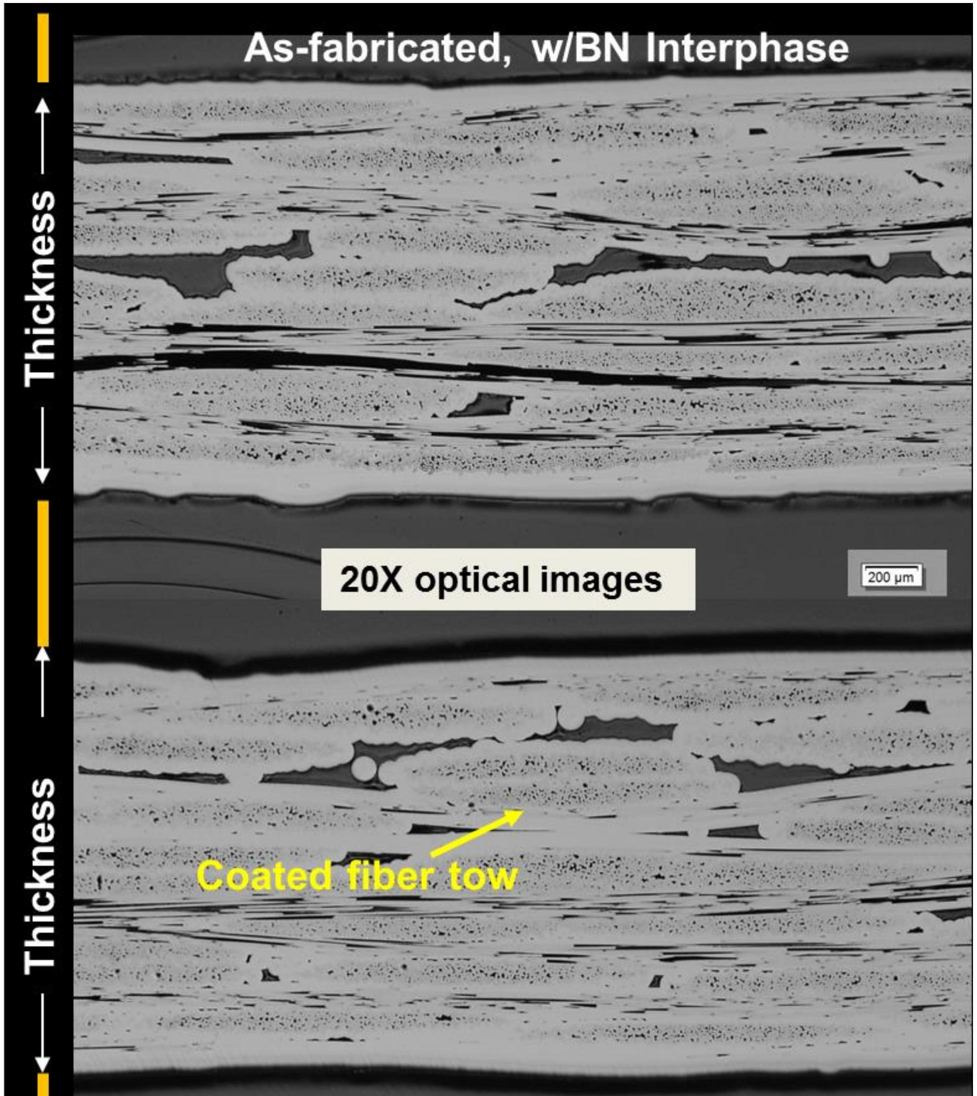
Objectives

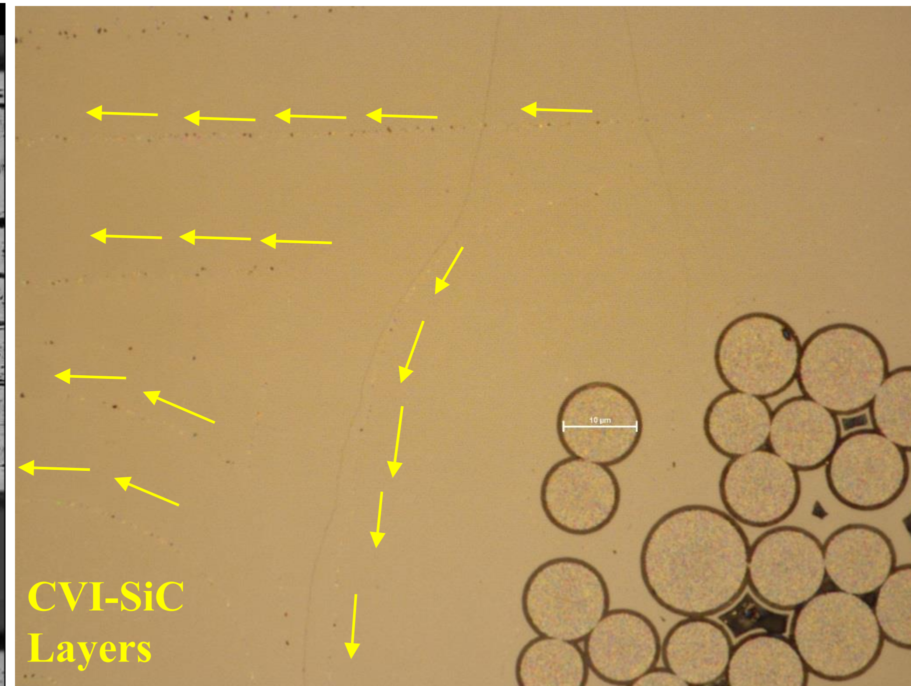
- Evaluation of CVI SiC/SiC Composites for High Temperature Applications.
- Establish stress-dependent and temperature-dependent parameters for modeling SiC/SiC composite creep behavior.
- Assess durability at 2200°F (1200°C) to 2700°F (1482°C) in air while under different mechanical loadings for up to several hundreds of hours.
- Determine post-creep retained mechanical properties.

Approach

- Conduct CMC constant temperature and stress creep, variable temperature creep, variable stress creep and sustained peak low-cycle fatigue testing from 2200°F (1200°C) to 2700°F (1482°C)—with a limited number of specimens.
- Apply stresses below the onset of matrix cracking stress.
- Examine samples that survived during the 2700°F (1482°C) testing (run-out condition) and characterize their residual properties / integrity at room temperature with the use of acoustic emission composites health monitoring technique.

CMC Material



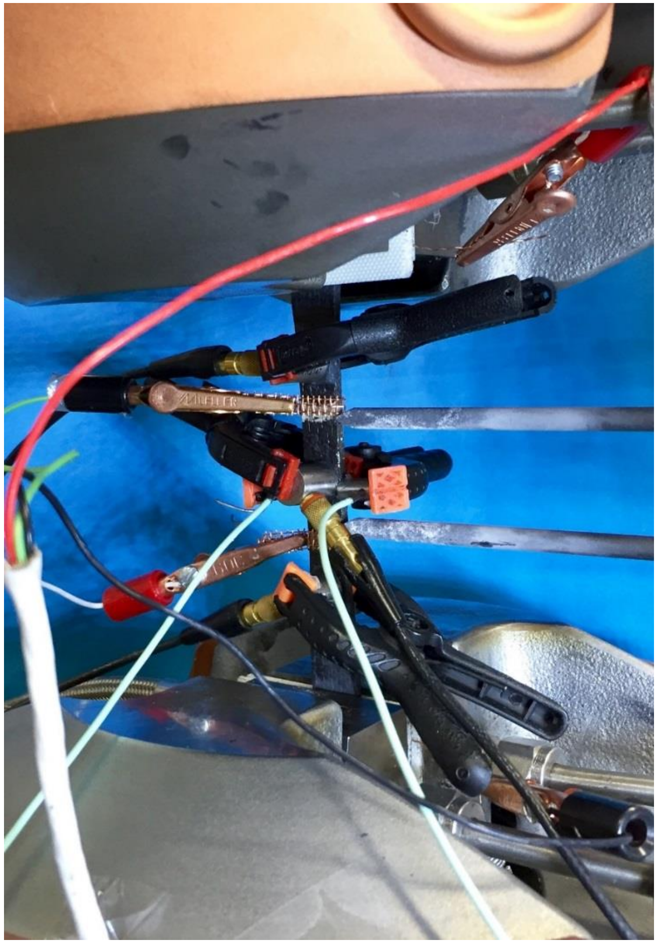


Loading Direction

- 2D CVI (chemical vapor infiltration) SiC/SiC reinforced with ~30% Sylramic^{TM}-iBN SiC fabric. ~11% Porosity *(Variable throughout samples).*
- ***Muiltilayered CVI-SiC Matrix.***
- Machined tensile samples were CVI SiC seal-coated to seal the coupons' edges.
- Made by Hyper-Therm *(Rolls-Royce HTC Now)* (via NASA LaRC-funded SBIR Phase II Contract NNX11CB63C).
- *Relevant material system, especially for 2700°F applications.*

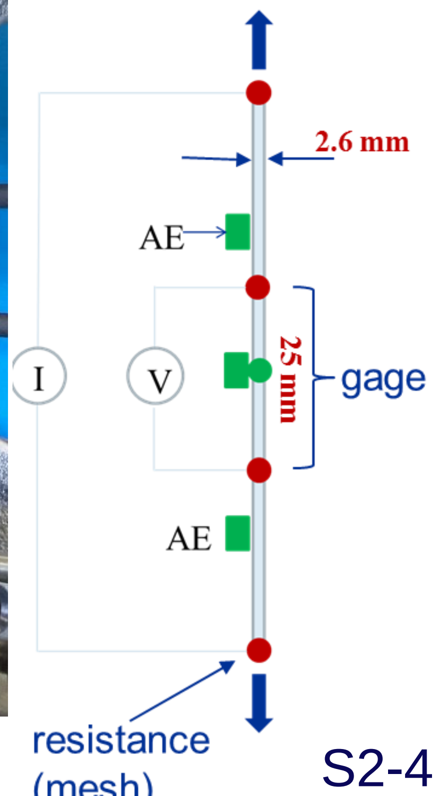
2D CVI SiC/SiC Reinforced with Sylramic^{TM}-iBN: Testing at Room Temp.: As-Rec. and Following Creep in Air

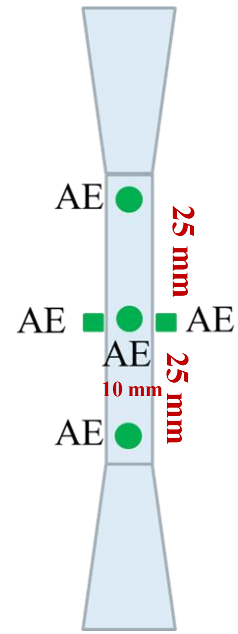
Used various characterization approaches (Acoustic emission (AE), resistivity, hysteresis testing, metallography and fractography)

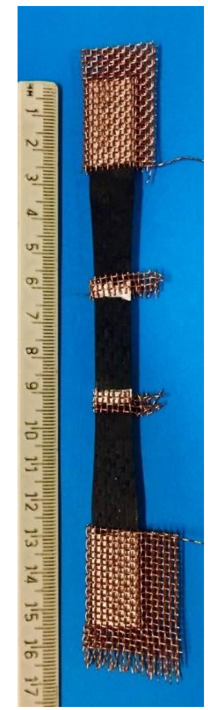


S2-6 (Post-creep)

Unique Acoustic Emission (AE) Set-up





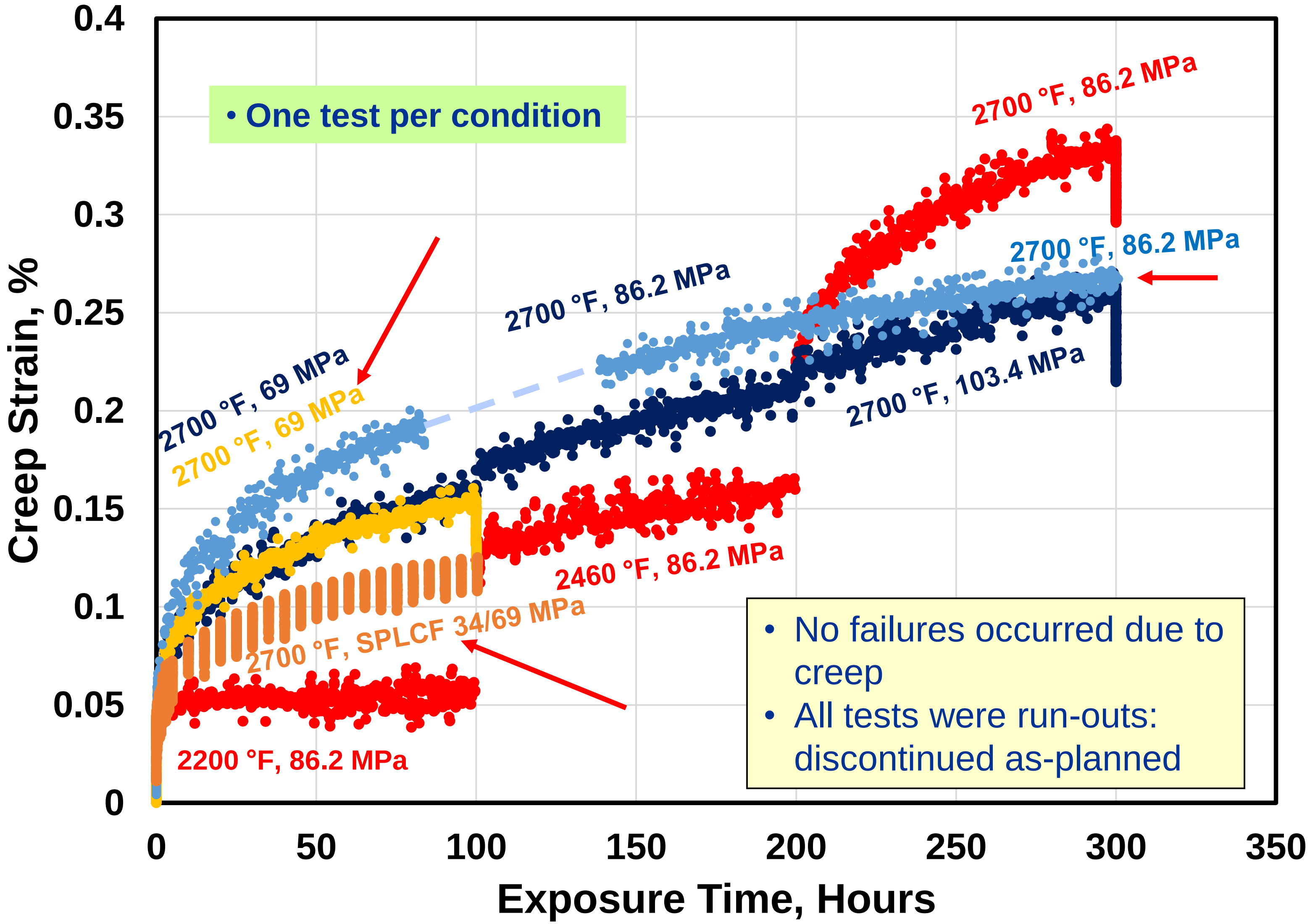


S2-4 (As-Fabricated Sample)

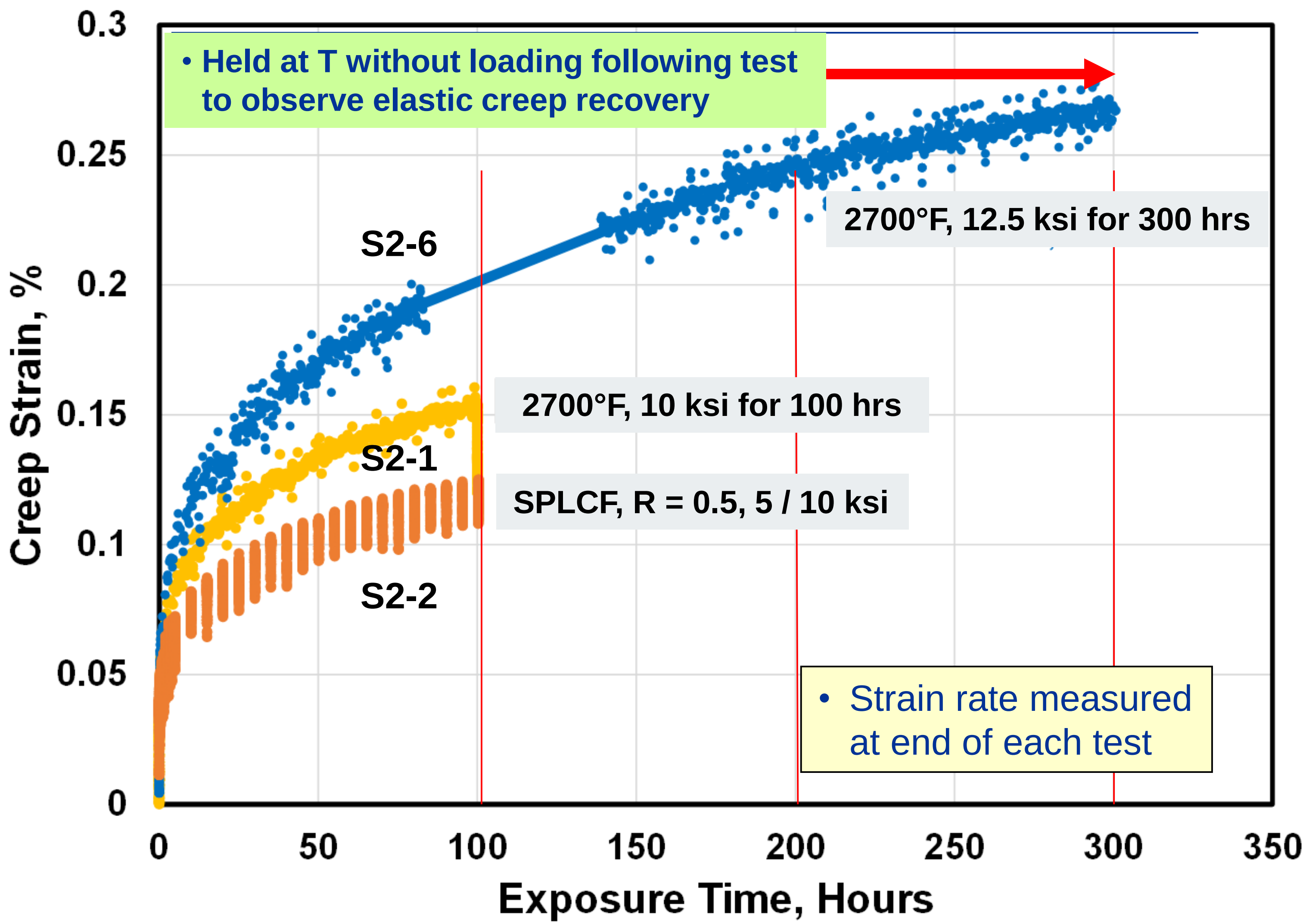
Prepped for Resistivity Measurement

High-Temperature Tests Results

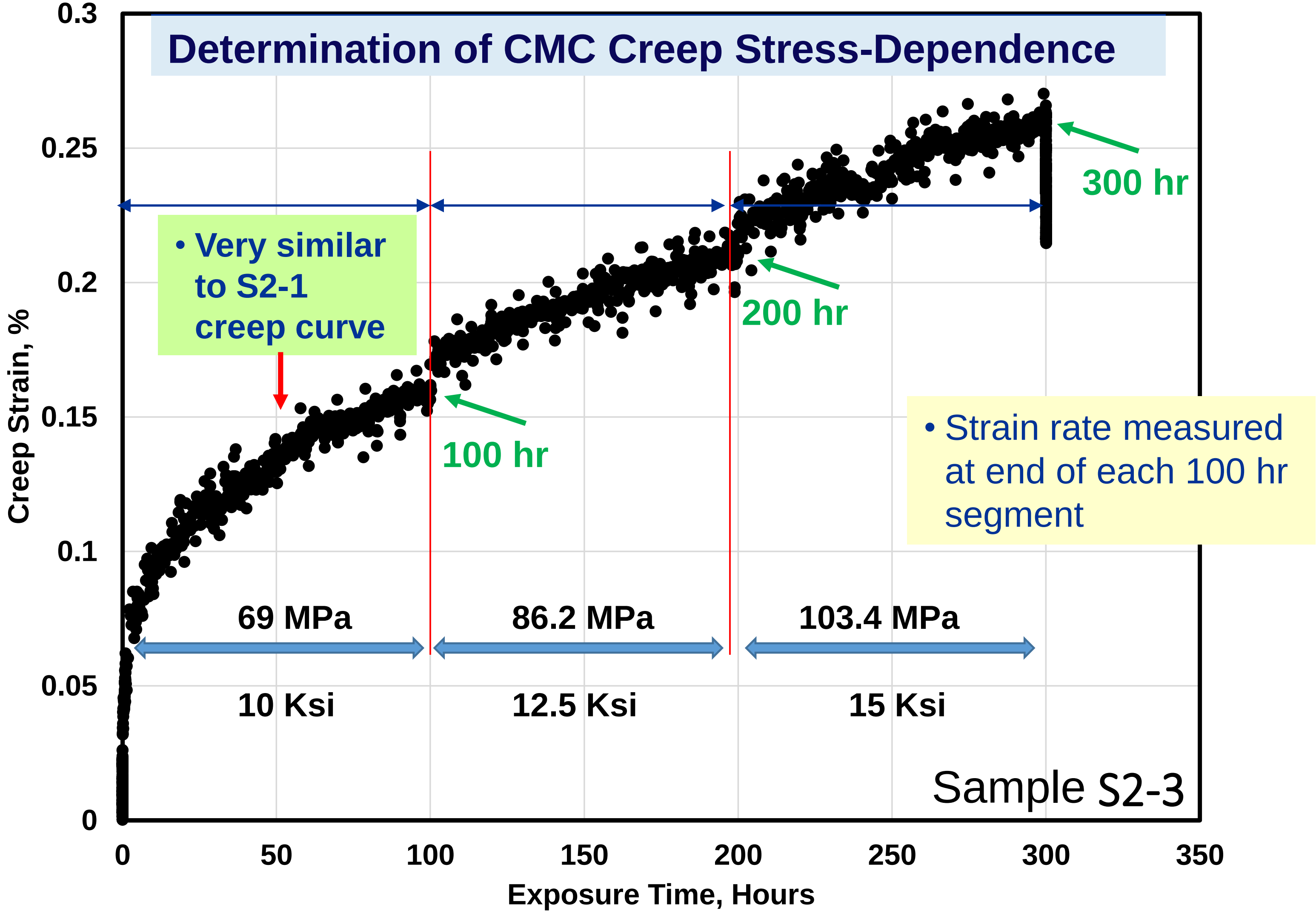
2D CVI SiC/SiC Reinforced with Sylramic™-iBN:
Creep in Air— *Results of 5 different testing conditions*



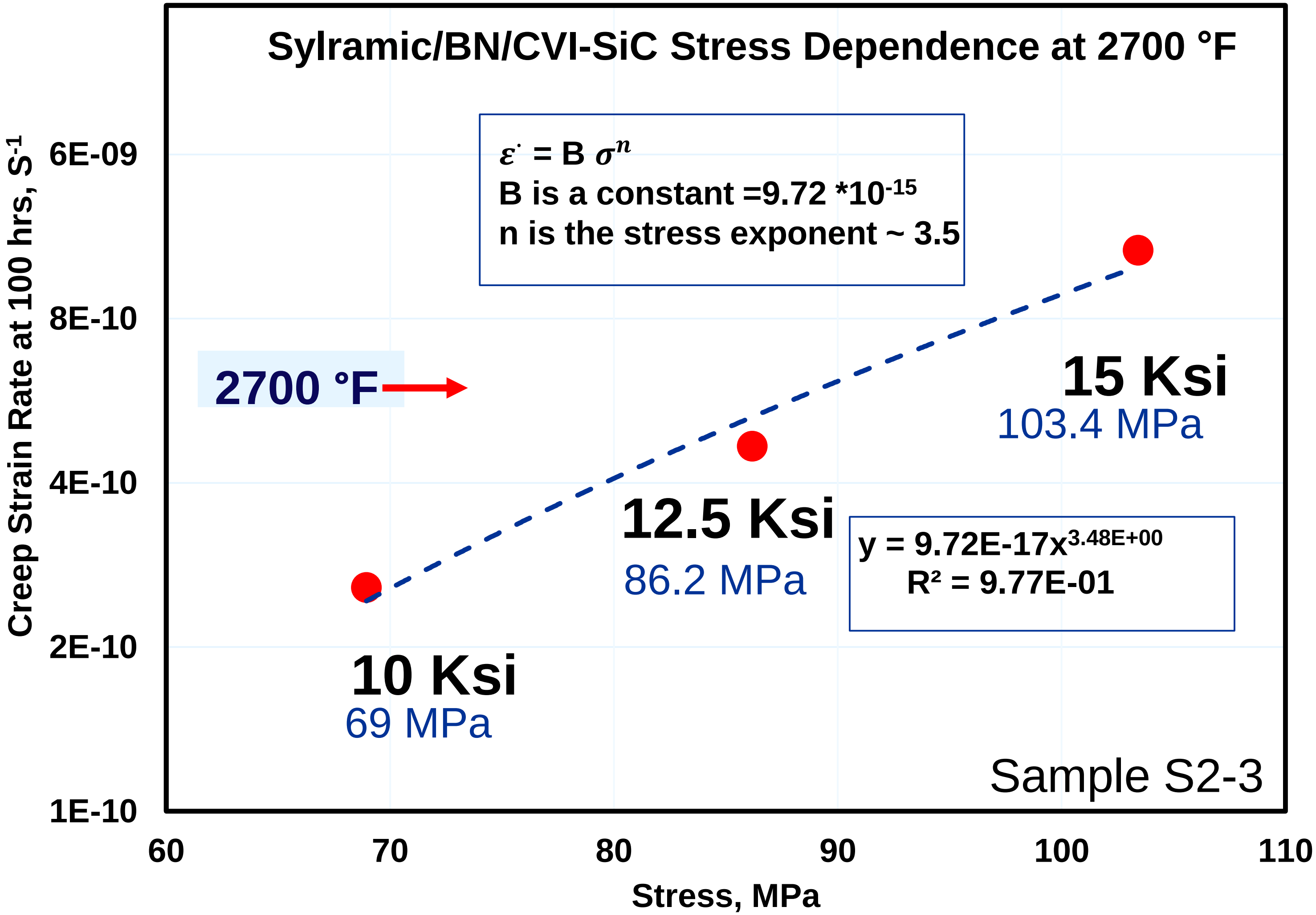
2D CVI SiC/SiC Reinforced with Sylramic™-iBN: Creep and SPLCF in Air at 2700°F (1482°C)



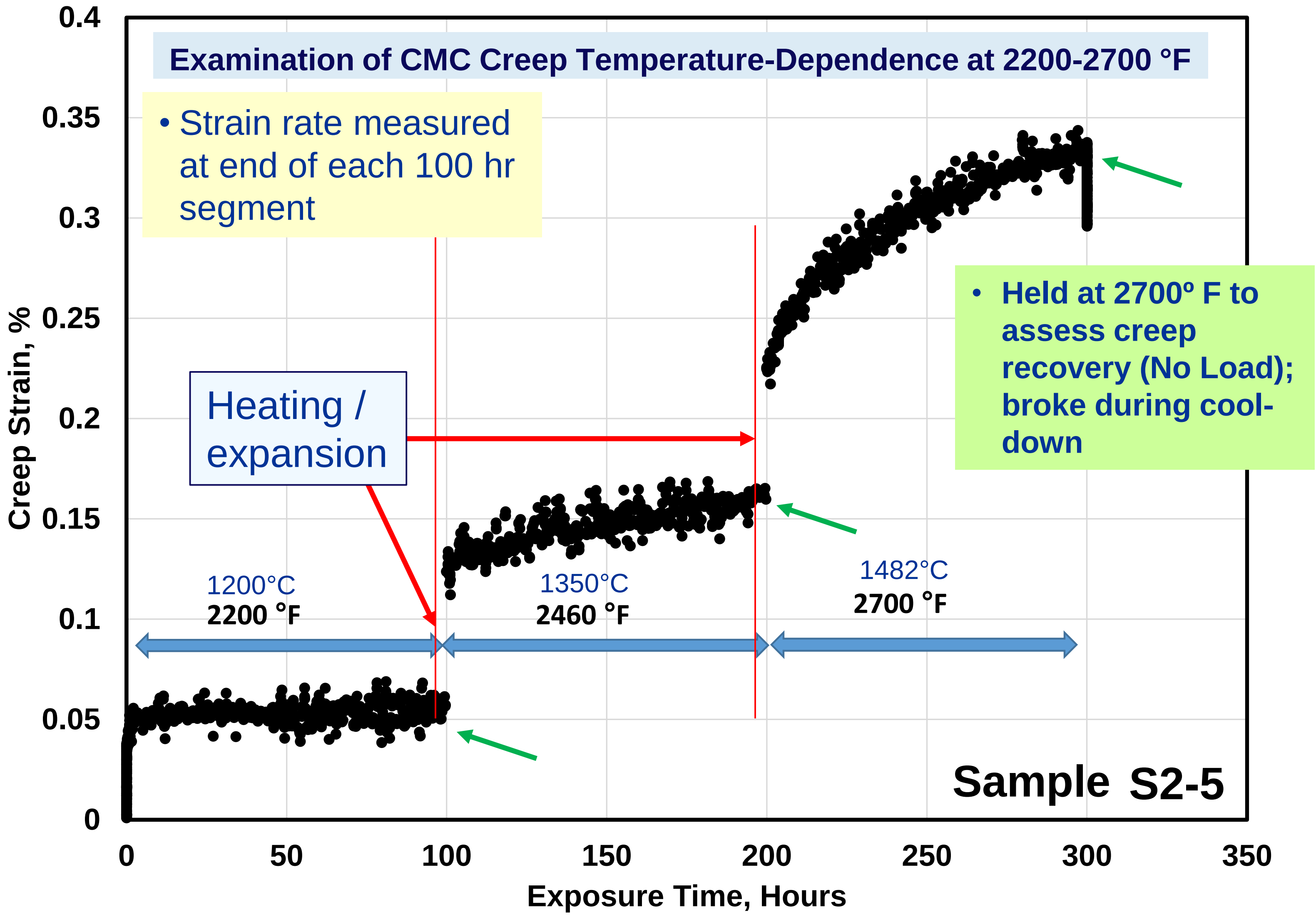
2D CVI SiC/SiC Reinforced with Sylramic^{TM}-iBN: Creep in Air at 2700°F (1482°C)— *Exposed to 3 stresses*



2D CVI SiC/SiC Reinforced with Sylramic™-iBN: Creep in Air at 2700°F (1482°C)



2D CVI SiC/SiC Reinforced with Sylramic™-iBN: Creep in Air, 12.5 ksi (86.2 MPa)—Exposed to 3 Temperatures



2D CVI SiC/SiC Reinforced with Sylramic™-iBN:
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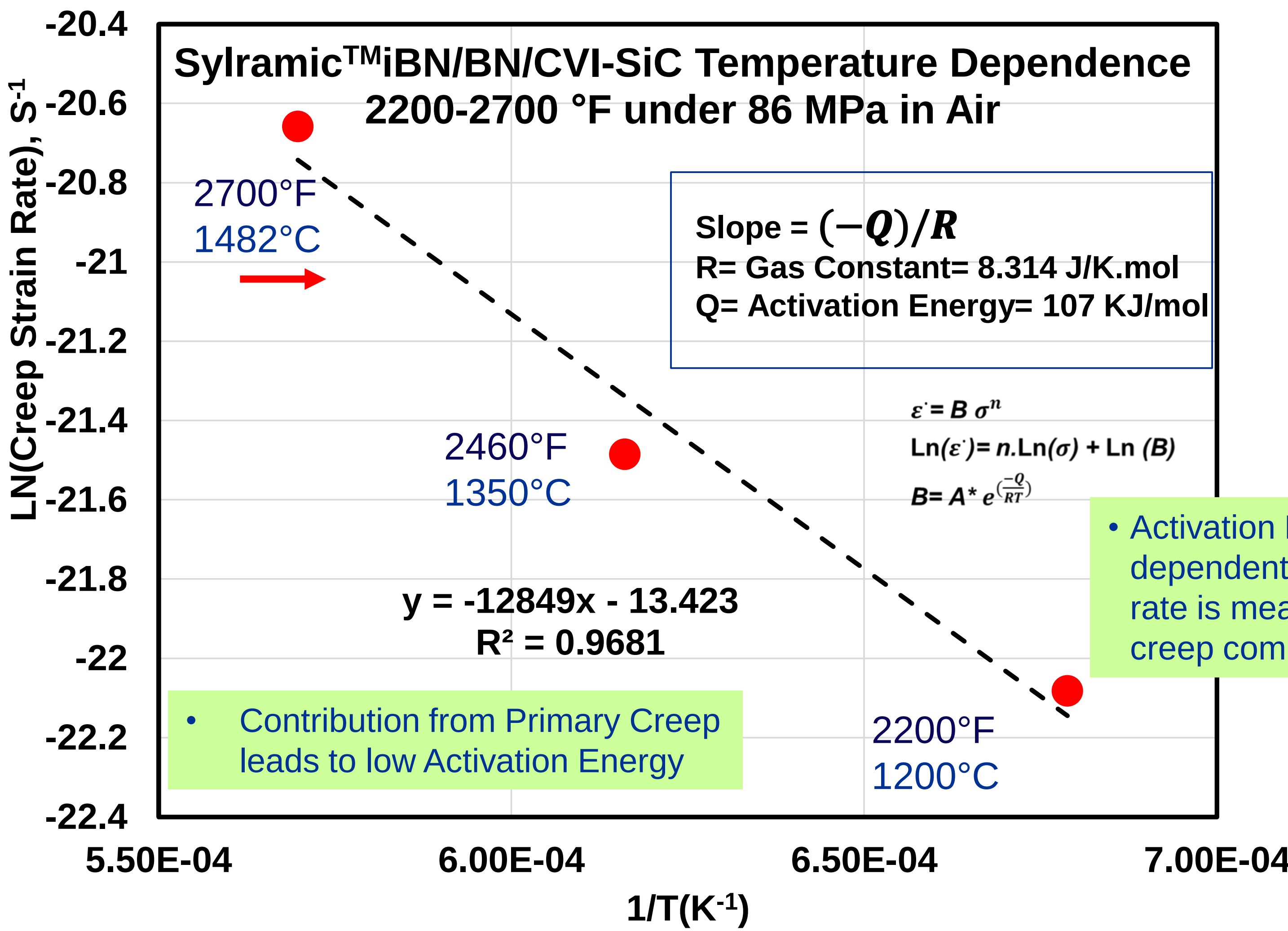
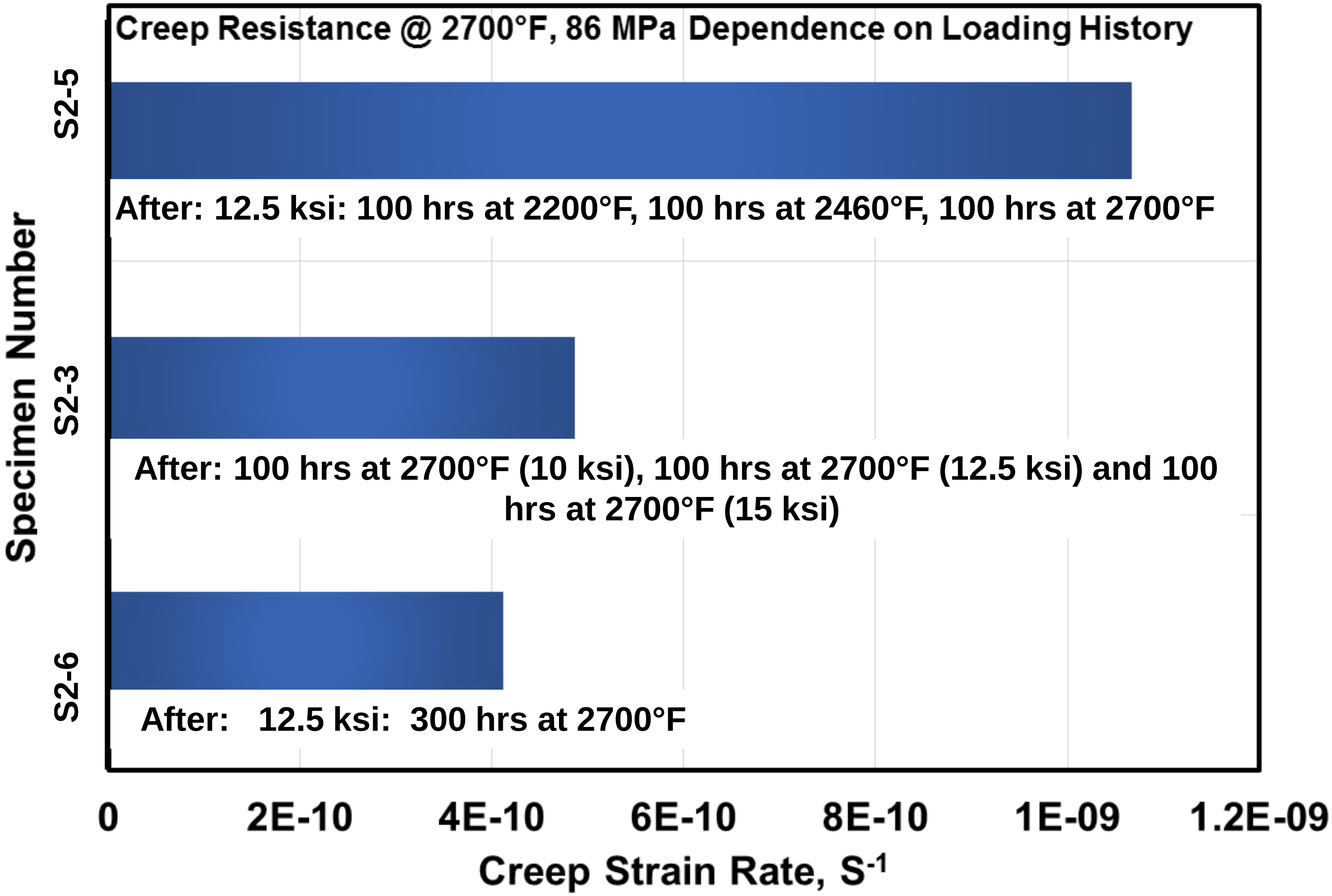


- Activation Energy is dependent on <u>when</u> strain rate is measured (hrs of creep completed)

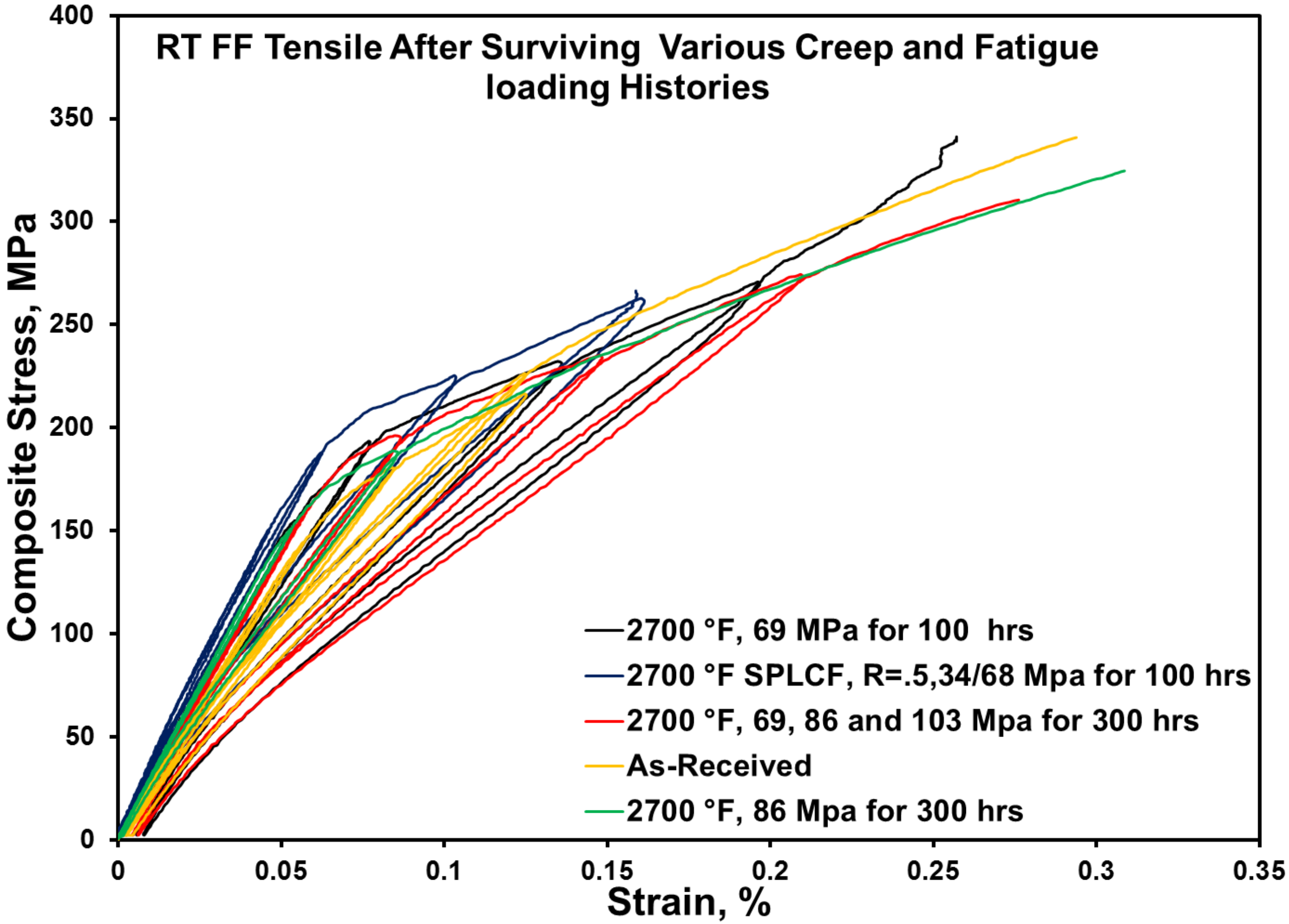
CMC Creep Dependence on Mechanical and Thermal Loading Histories

Example of How Measured Strain Rate Depends on Loading History



Room-Temperature Tests Results

RT FF Tensile Tests with Hysteresis Loops Results



- Post creep RT FF UTS results were similar to that for as-received sample.
- No fiber degradation.

Test Results Summary

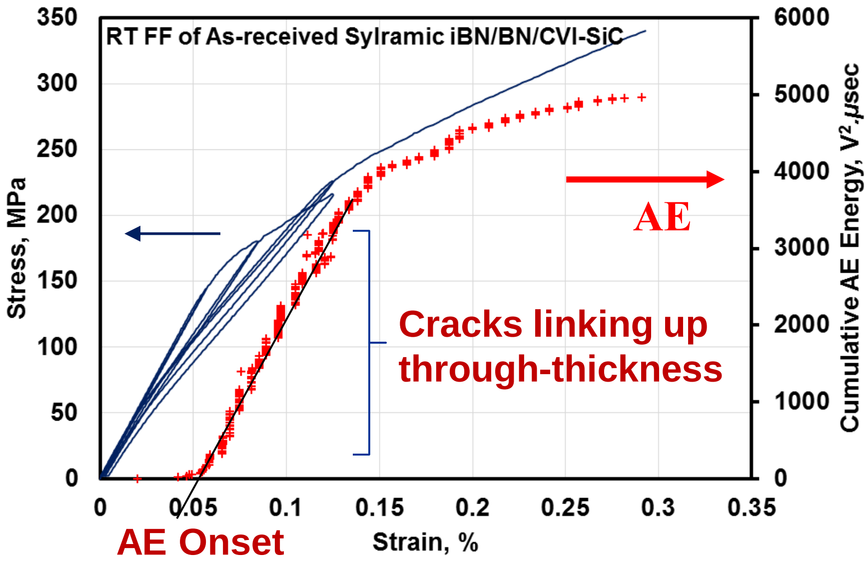
Specimen ID	Test Condition (Temperature °F, Stress MPa, Time Hours)	Elastic Modulus, GPa	Residual UTS, MPa	Ultimate Creep Strain, %	σ_{th}, MPA	ρ_c, mm^{-1}	Ultimate Strain, %	Stress at Onset of Matrix Cracking, MPa	Thickness, mm	Fiber Content, %
1520-S2-1	2700 °F, 69 MPa for 100 Hours	302	341	0.15	50	9.53	0.26	145	2.53	15.69
1520-S2-2	2700 °F, SPLCF, R=0.5, 34/69 MPa for 100 Hours	365.9	355	0.12	60	9.35	0.18	163	2.62	15.15
1520-S2-3	2700 °F, 69 MPa for 100 Hours, 86 MPa for 100 Hours, 103 MPa for 100 Hours	281	311	0.26	55	8.11	0.28	157	2.5	15.88
1520-S2-4	RT Tensile test	261.7	341	0	40	9.16	0.33	119	2.73	14.54
1520-S2-5	2200 °F, 86 MPa for 100 Hours, 2460 °F, 86 MPa for 100 Hours, 2700 °F, 86 MPa for 100 Hours	-	Broke upon cooling	0.34 (0.2)	-	-	-	-	2.64	15.03
1520-S2-6	2700 °F, 86 MPa for 300 Hours	296	325	0.26	52	8.37	0.31	150	2.6	15.27

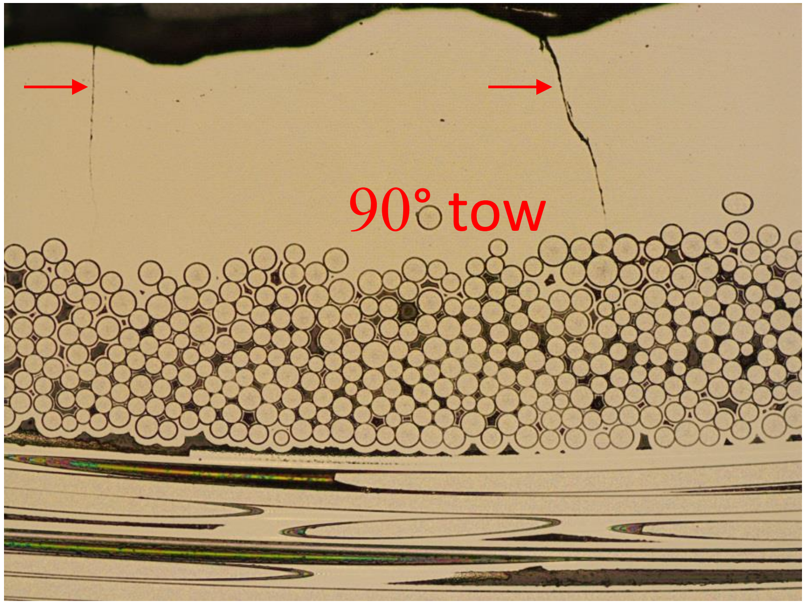
- Samples from gage sections were cut and polished and crack densities were measured.
- AE provided good estimate for the stress at the onset of CVI-SiC matrix cracking.

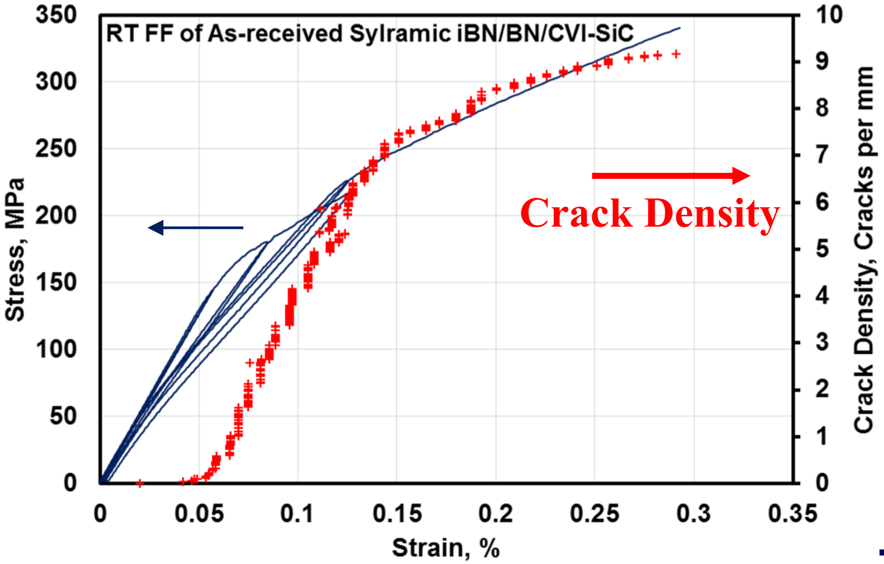
Differences in the elastic modulus and matrix cracking stresses could be due to:

- Different creep and fatigue loading histories.
- Different porosity content.
- Difference in fibers content in loading direction.

RT Fast Fracture Tensile Tests Results:
Stress & Acoustic Emission Vs. Strain

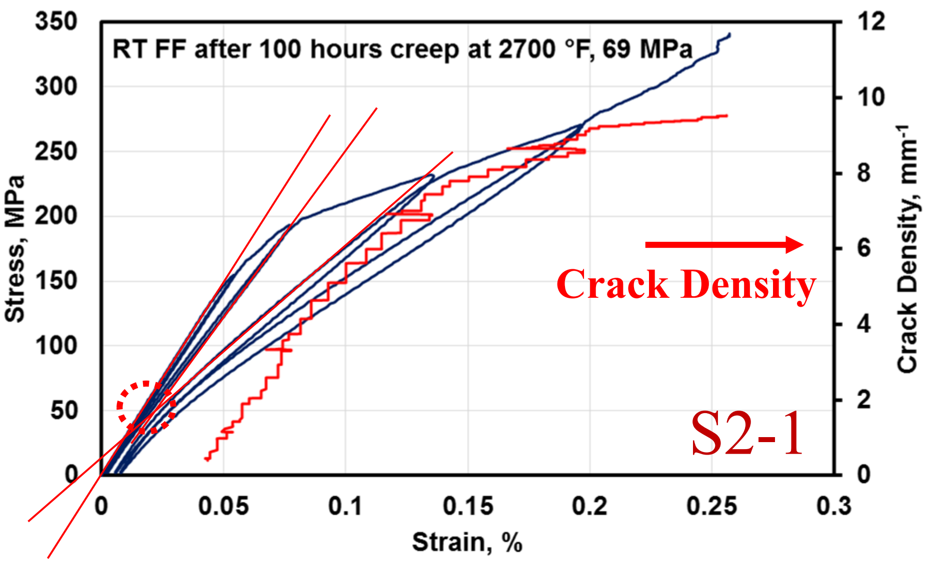


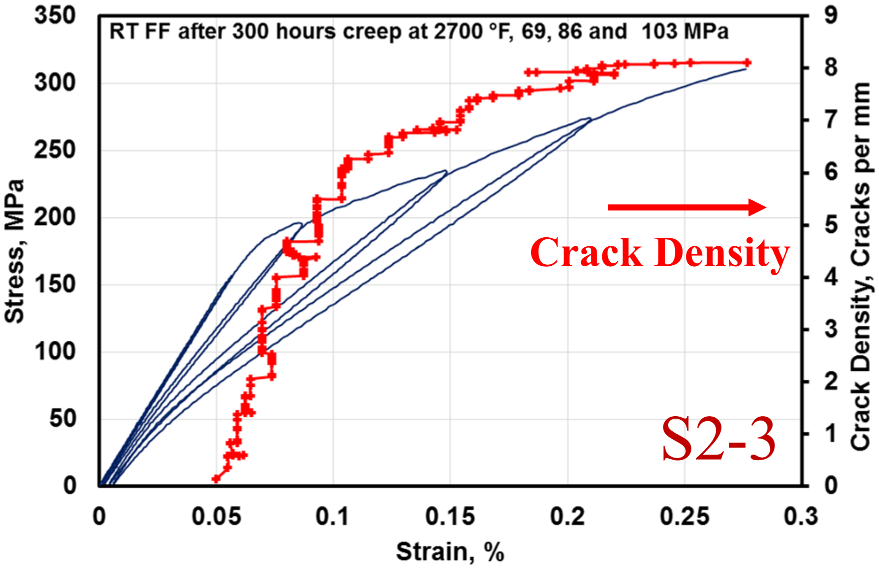




- Samples were cut from gage sections and polished, and crack densities were measured.
- AE provided a good estimate for the onset and progression of damage.
- Crack Density Evolution of Sylramic™ iBN/BN/CVI-SiC was obtained from the multiplication of the normalized AE evolution by the measured CVI-SiC crack density at failure.

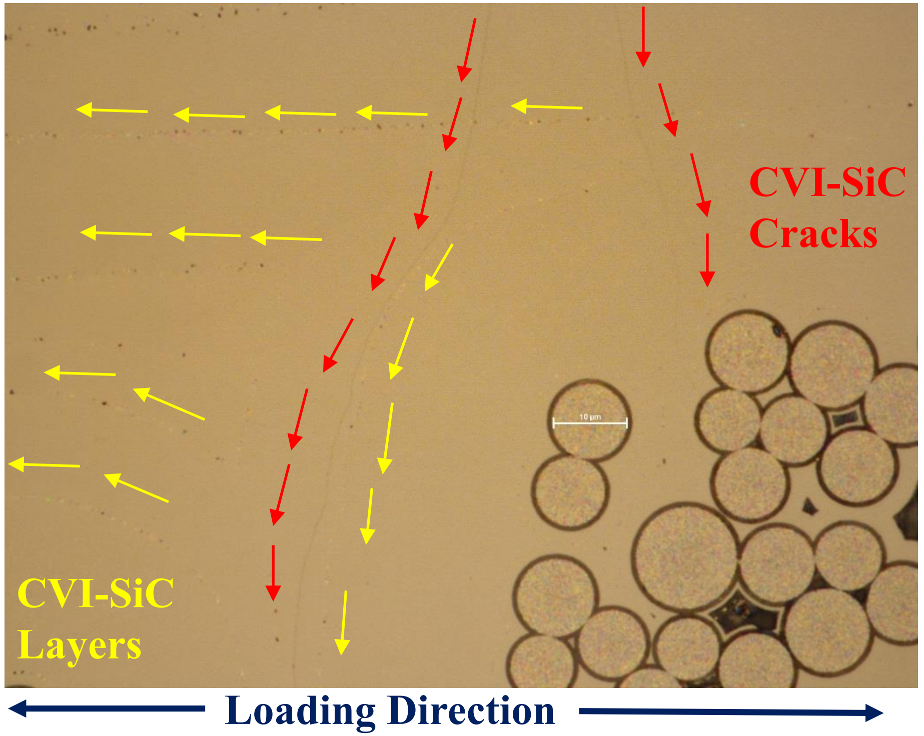
RT Post Creep Fast Fracture Tensile Tests Results



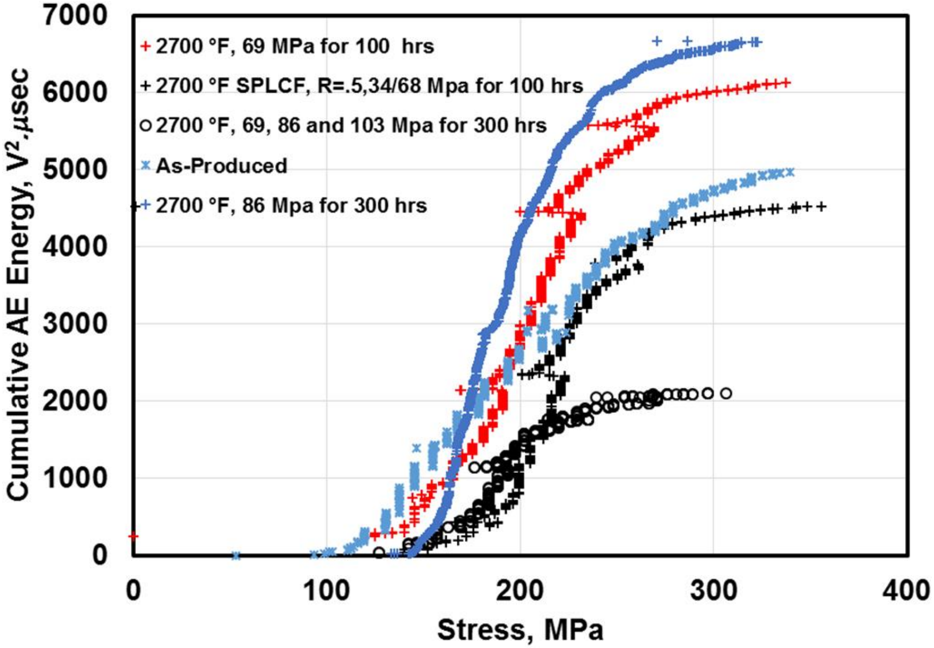


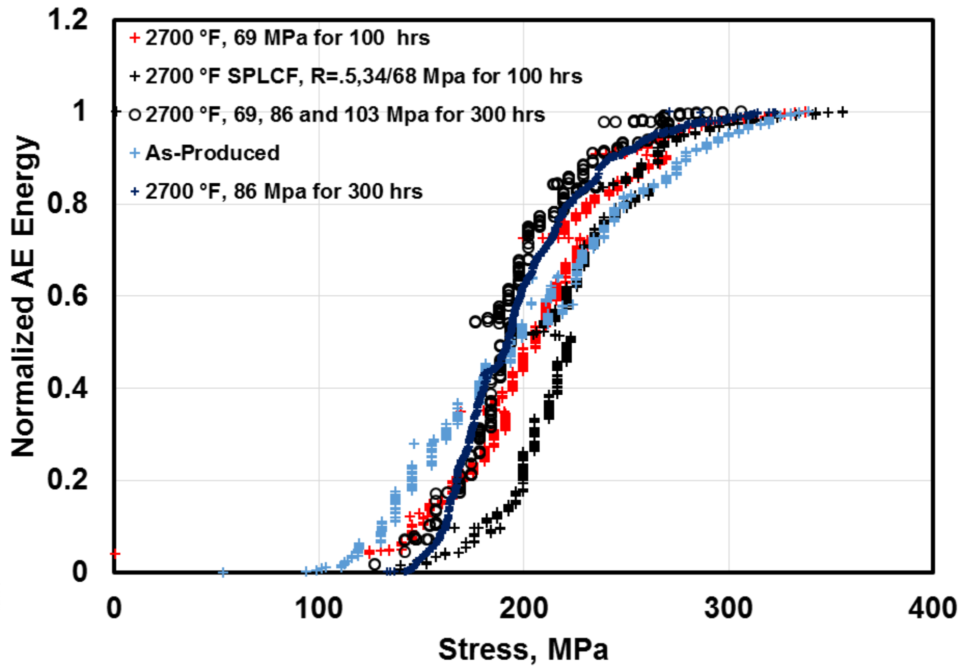
- Compressive residual stress values were obtained using the intersection of the tangents of the loading portions of the hysteresis loops*.

*Steen M, Valles JL. ASTM STP 1309. In: Jenkins MG et al., editors. West Conshohocken, PA: American Society for Testing and Materials; 1997. p. 49–65.



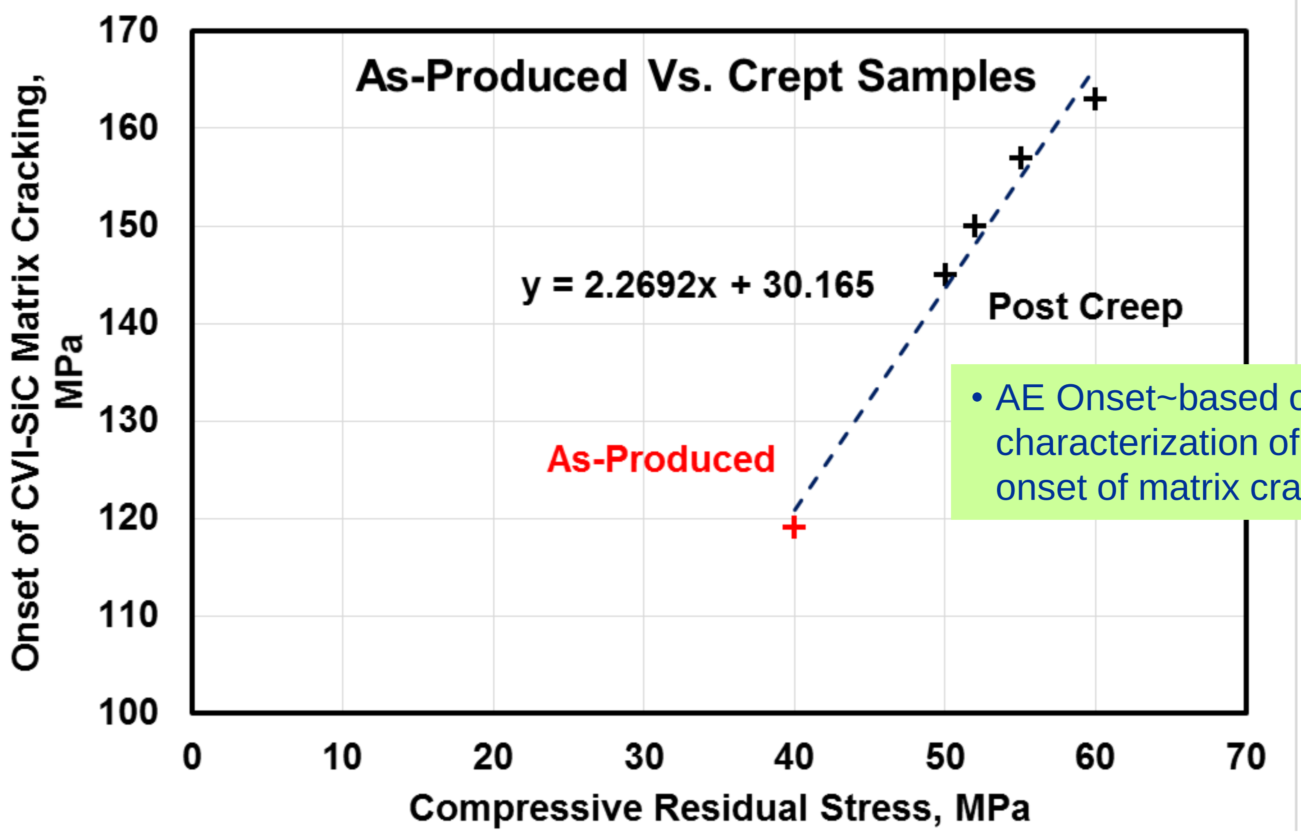
AE Energy Evolution of Sylramic™-iBN/BN/CVI-SiC with Different Creep Loading Histories





- AE provided good estimate for the onset and progression of damage.
- Absolute AE energy evolution of Sylramic™ iBN/BN/CVI-SiC samples correlates with stress dependent matrix cracking after different creep loading histories.
- Cracking evolution of Sylramic™-iBN/BN/CVI-SiC is dependent on the different creep loading histories.

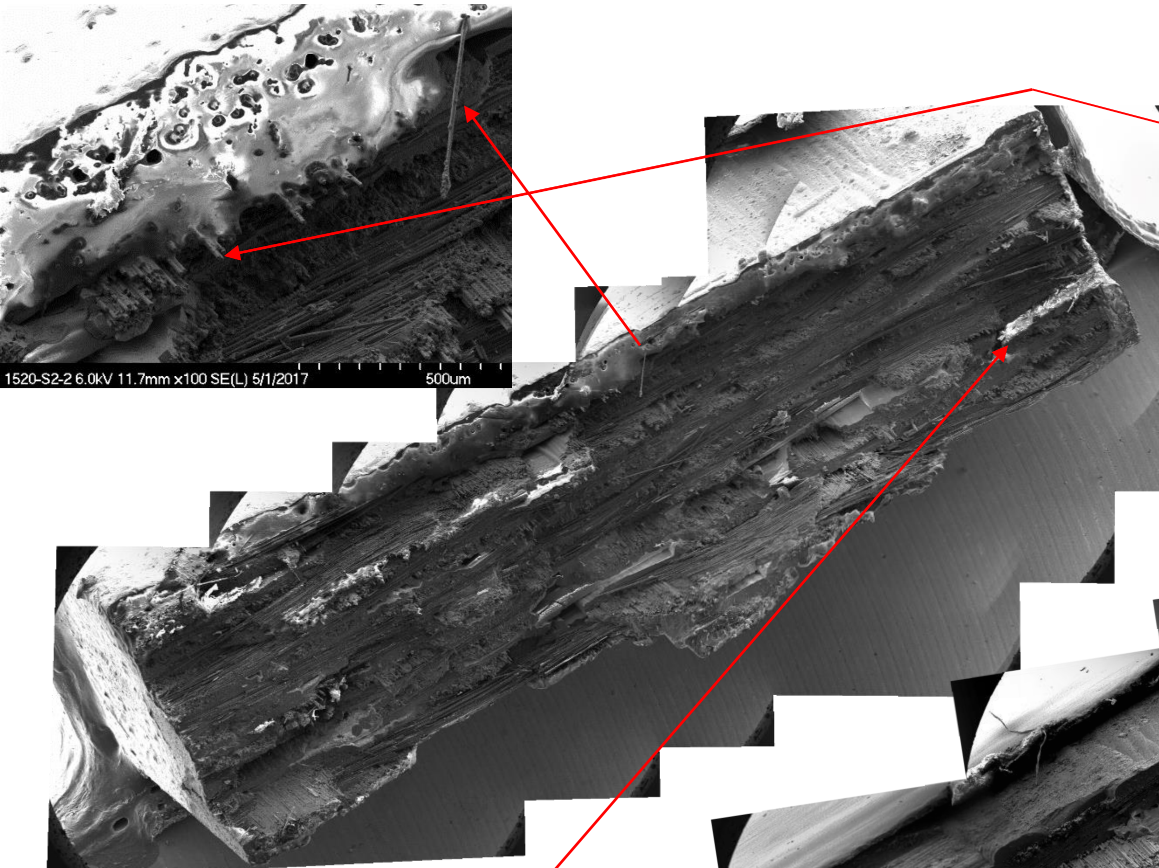
Creep and Low-Cycle Fatigue at 2700°F Effect on the Stress at the Onset of CVI-SiC Cracking

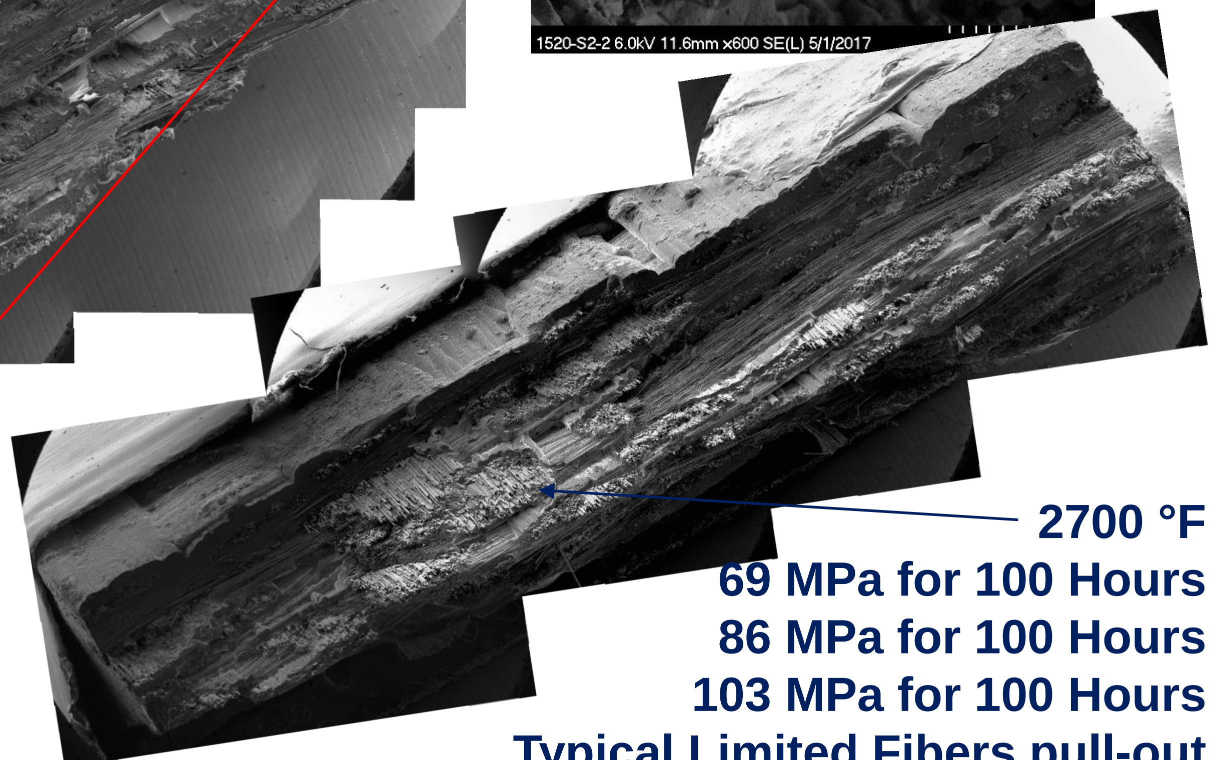


- AE Onset~based on AE characterization of the onset of matrix cracking

➢ Creep and low-cycle fatigue exposure at 2700°F (1482°C) induced additional compressive thermal residual stress on the CVI-SiC which may have caused the increase in the stress at the onset of CVI-SiC matrix cracking in post creep FF testing.

Fracture Surfaces





2700 °F
SPLCF, R=0.5
34/69 MPa for 100 Hours
Oxidation

2700 °F
69 MPa for 100 Hours
86 MPa for 100 Hours
103 MPa for 100 Hours
Typical Limited Fibers pull-out

Summary and Conclusions

- CVI SiC/SiC CMCs incorporating Sylramic™-iBN SiC fiber were evaluated via tensile creep testing to determine creep parameters for modeling. A stress exponent was determined at 2700°F, and an activation energy was calculated.

- Post creep RT FF ultimate tensile strength results were similar to that for as-received samples (no fiber degradation).

- Acoustic emission energy data analysis provided a good estimate for the onset and evolution of damage during RT FF testing.

- Creep resistance differential between the constituents of Sylramic™-iBN/BN/CVI-SiC induced compressive thermal residual stress, which may have caused the increase in the stress at the onset of CVI-SiC matrix cracking in post creep FF testing.

- Examination of fracture surfaces indicated CVI-SiC microcrack formation and oxidation during low cycle fatigue testing at stresses below the RT matrix cracking stress.

- More analysis of acoustic emission side sensors' waveforms will be performed.